Which Metric of Relative Weight Best Captures Body Fatness in Children?

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Abstract

FIELD, ALISON E., NAN LAIRD, EMILY STEINBERG, ERICA FALLON, MARIAMA SEMEGA-JANNEH, AND JACK A. YANOVSKI. Which metric of relative weight best captures body fatness in children? *Obes Res.* 2003;11:1345–1352.

Objective: To evaluate the relative merits of BMI (kilograms per meter squared) and age- and gender-adjusted BMI, age- and gender-specific z score of BMI, and age- and gender-specific percentiles of BMI as surrogate measures of body fatness among a sample of youth.

Research Methods and Procedures: The sample comprised 596 children and adolescents 5 to 18.7 years old and was 40% male and 55% white. Height and weight were measured by trained research staff. DXA was used to determine body fat mass. BMI, age- and gender-specific percentile of BMI, and age- and gender-specific z scores of BMI were computed, and these metrics were compared with measured body fatness.

Results: The BMI values in the sample ranged from 12.9 to 55.0 kg/m^2, with a mean of 24.9 kg/m^2. The Spearman correlations with percentage body fat were similar for all of the BMI metrics (r = 0.82 to 0.88). Linear regression models with age- and gender-specific percentiles of BMI explained significantly less of the variance (65%) than models with log-transformed BMI (81%) or age- and gender-specific z scores of BMI (75% to 79%). z scores were the most accurate at classifying children who were overfat (sensitivity = 0.84, specificity = 0.96 for z score $\geq$1). However, using a BMI $\geq$85th percentile or a BMI $\geq$20 kg/m^2 was also accurate at classifying youth.

Discussion: The BMI metrics had similar correlations with body fatness, but age- and gender-specific percentiles of BMI were the least accurate proxy measure of body fatness. However, a BMI z score $\geq$1, BMI percentile $\geq$85, and BMI $\geq$20 kg/m^2 are all useful for identifying children who may be overfat.

Key words: BMI, body fat, BMI percentile, *z* scores of BMI, measurement

Introduction

Obesity is a growing and serious public health problem among children, adolescents, and adults in the U.S. During the past 2 decades, the prevalence of overweight has increased by more than 100% among adolescents in the U.S. (1,2), and the trend appears to be continuing. Because preadolescents and adolescents who are overweight are likely to become overweight adults (3), it suggests that it is essential to target youth for obesity prevention messages and intervention programs.

To judge the effectiveness of prevention programs and to enable clinicians to decide whether a patient is in need of intervention, it is essential that one can easily measure changes in body fatness and relative weight. The gold standard for measuring body fat is hydrodensitometry or radiographic techniques such as DXA. Unfortunately, these methods of measurement are labor intensive, expensive to collect, and require skilled personnel. Therefore, it has not been feasible to collect these types of data in general clinical settings or large epidemiological studies. As a result, weight and height are the only measures that are obtained in many settings. Thus, is it not surprising that there has been a move to define weight status in terms of BMI (weight in kilograms/height in meters squared) or other metrics of weight for height. Among adults, one can monitor changes in weight and evaluate these changes on their own or in terms of BMI. There are established cutoff values of BMI that

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apply to both genders and across a wide age range among adults to indicate when treatment is appropriate and when relative weight is excessive (4). Unfortunately, it is more complicated to evaluate BMI or relative weight among children and adolescents because increases in weight and height are part of development; thus, one must have information on age to interpret BMI. Moreover, due to gender differences in body fatness, timing of puberty, height change, and height velocity, it is essential to interpret BMI in the context of age and gender.

Although many papers have reported on the degree of association between BMI and body fatness (5–9), the BMI percentiles and *z* scores based on the new Centers of Disease Control and Prevention (CDC)[1]-issued charts have been evaluated as proxy measures of fatness only in one study (10). Overall, BMI has been found to have a strong correlation with body fatness among preadolescents and early adolescents (7,8,11). Given the wide spread use of BMI for age and BMI percentile for age, it is important to evaluate these metrics as proxy measures of body fatness among multiracial youth. We compared measures of body fatness with BMI, BMI adjusted statistically for age and gender, age- and gender-specific *z* score of BMI, and age- and gender-specific percentiles of BMI to evaluate the relative merits of various measures based on BMI as proxy measures of body fatness among a sample of youth.

Research Methods and Procedures

Sample and Procedure

The sample comprised 596 children (5.5 to 18.7 years of age). The sample was 40% boys ($n = 237$), 55% white ($n = 330$), and 40% ($n = 239$) African American. Participants were recruited through two waves of notices mailed to first through fifth grade children in the Montgomery County and Prince Georges County, MD school districts and two mailings to local family physicians and pediatricians. Mailings to families requested participation of healthy children willing to undergo phlebotomy and roentgenograms. Mailings to physicians requested overweight children willing to participate in similar studies and also specified that no treatment would be offered. Approximately 7% of families responded to each of the school mailings, and subjects recruited directly from these mailings constituted 72% of all subjects studied. None of the children accepted into the study were undergoing weight loss treatment, and all were aware that they would not receive treatment as part of the study protocol or after participation. Participants were medication-free for at least two weeks before being studied, and none had significant medical disease. Each child had normal hepatic, renal, and thyroid function. Children provided written assent, and parents gave written consent for participation in the protocol. This study was approved by the National Institutes of Child Health and Human Development Institutional Review Board.

Information on race/ethnicity of each subject and of each subject's four grandparents was self-reported, and age was calculated from date of birth. Measurement of height (measured three times to the nearest 1 mm) was performed using a stadiometer (Holtain Ltd., Crymmych, Wales, United Kingdom) calibrated before each child's height measurement to the nearest 1 mm. Weight to the nearest 0.1 kg was obtained using a calibrated digital scale (Scale-Tronix, Wheaton, IL).

Each participant also underwent a DXA scan (in the pencil beam mode; Hologic QDR-2000, Waltham, MA) for determination of body fat mass. Findings from DXA fat mass measurements have demonstrated excellent reproducibility in children ($r > 0.96$, inter assay coefficient of variation $< 6\%$) (12), and a growing body of evidence indicates that DXA is an accurate method of quantifying fatness in small animals (13), children (14–16), and obese adults (17).

Pubertal breast and pubic hair stage and testicular volume were assessed by a physician or pediatric nurse practitioner according to the standards of Tanner (18). The measured weight and height information was used to compute BMI, age- and gender-specific percentile of BMI, and age- and gender-specific *z* scores of BMI. Two sets of *z* score values were computed, one based on the CDC growth charts (19), the other based on reference standards reported by Frisancho (20). The population in the latter standards was slightly leaner, and the method for determination of BMI *z* scores was the traditional approach (based on mean and SD), rather than the LMS method employed for the CDC charts.

To make the BMI-related metrics more comparable with each, BMI and log-transformed BMI were regressed on age and gender, and the residuals were used to assess the association of BMI, independent of age and gender, with percentage body fat. Associations with BMI and log-transformed BMI were also evaluated. All BMI metrics were centered at the mean value in the study.

To assess how well the BMI metrics could be used to screen for overfatness, BMI, BMI *z* scores, and BMI percentiles were made into a series of indicator variables that were compared against the age- and gender-specific cutoffs for overfatness that were proposed by Himes and Bouchard (21). The BMI values used as possible screening cutoffs were 19 to 25 kg/m^2 (the adult cutoff for obesity). The *z* scores and alternative *z* scores were dichotomized as ≥ 1, ≥ 2, and ≥ 3 *z* scores. The BMI percentiles were dichotomized as $\geq$85th and $\geq$95th percentiles, which the CDC defines as at risk of overweight and overweight, respectively.

[1] Nonstandard abbreviations: CDC, Centers of Disease Control and Prevention; PPV, positive predictive value; ROC, receiver operating characteristic.

Table 1. Demographic factors

	Total (n = 596)	Girls (n = 359)	Boys (n = 237)
Age (years)*	10.0 (2.2)	10.0 (2.2)	9.9 (2.3)
BMI (kg/m^2)*	24.9 (8.9)	24.7 (8.5)	25.3 (9.5)
Age- and gender-specific percentile of BMI*	80.9 (25.8)	79.8 (27.3)	82.5 (23.3)
% Body fat*	34.1 (12.6)	35.2 (11.8)	32.5 (13.6)
Race			
White	330 (55.4%)	178 (49.6%)	15 (64.1%)
African American	239 (40.1%)	157 (43.7%)	82 (34.6%)
Hispanic, Asian, or other	27 (4.5%)	24 (6.7%)	3 (1.3%)
At risk of overweight and overweight			
85th to 95th percentile of BMI (19)	73 (12.3%)	48 (13.4%)	25 (10.6%)
>95th percentile of BMI (19)	304 (51.0%)	180 (50.1%)	124 (52.3%)

* Mean (SD).

Methods

Spearman correlations were used for univariate comparisons of the BMI metrics with measured percentage body fat. Correlations were computed using the entire sample and within gender. The BMI metrics were further compared in terms of the percentage of the variance of linear regression models they explained. By design, the sample was heavily skewed upwards, with a large proportion of children above the 95th BMI percentile for age and gender; thus, none of the measures were normally distributed. Several approaches were taken to assess whether the skewness of the distribution had an impact on the results. In linear regression models, BMI was evaluated in terms of BMI and log-transformed BMI. Percentage body fat was not highly skewed; therefore, it was not log transformed. Measures were also centered around the mean value. In addition, subanalyses were run, restricting the sample to children at or below the national 99th age- and gender-specific percentile of BMI (n = 418).

The relationship between age and body fat was not linear; hence, we included an additional term for age squared so that the regression models would better fit the data. Age (modeled as age and age squared) and gender were statistically adjusted for in all linear regression models. Race and Tanner stage were also included in a subset of models. Race was a dichotomous variable (black vs. white), with whites as the reference group. We modeled Tanner stage in two ways. In one set of analyses, we modeled Tanner stage as a series of indicator variables: Tanner 1, Tanner 2, Tanner 3, or Tanner 4 or 5. In other analyses, we modeled Tanner stage as a categorical variable. In all the models that adjusted for Tanner stage, Tanner stage 1 was the reference group. To assess whether the percentage of the variance the metrics explained varied by gender, race, or age, the analyses were rerun stratified on the variable of interest (e.g., gender). SAS version 8.2 (SAS, Inc., Cary, NC) was used for all analyses (22). To compare the performance of the metrics, we used the nonstandard application of general estimation equation methods proposed by Pepe et al. (23). To compare the metrics in ability to correctly classify individuals in terms of overfatness (based on body fat standards that were proposed by Himes and Bouchard) (21), sensitivity, specificity, positive predictive values (PPVs), and receiver operating characteristic (ROC) curves were used (24).

Results

The BMI values in the sample ranged from 12.9 to 55.0 kg/m^2, with a mean of 24.9 kg/m^2. Approximately 43% (n = 257) of the children had a BMI of at least 25 kg/m^2, the adult cutoff for overweight. Using the pediatric cutoff for overweight, which is having a BMI greater than the national 95th age- and gender-specific percentile, 51% (n = 304) of the children were overweight, and an additional 73 (12.2%) were at risk of overweight (i.e., had a BMI between the 85th and 95th percentiles) (Table 1).

BMI had a stronger correlation (Spearman $r = 0.54$) than the other BMI metrics (r = 0.26 to 0.28) with age (Table 2). Age had a modest correlation with percentage body fat (Spearman $r = 0.34$); thus, to avoid confounding by age, which would inflate the associations with BMI, it was necessary to regress BMI on age and gender to create another BMI variable to compare with the other BMI metrics. The Spearman correlations with percentage body fat were similar for age- and gender-adjusted BMI ($r = 0.82$), age- and gender-specific z scores of BMI (r = 0.87 to 0.88), and age- and gender-specific percentile of BMI ($r = 0.88$)

Table 2. Spearman correlations of BMI metrics with age, Tanner stage, and percentage body fat

	Total (n = 596)			Boys (n = 237)			Girls (n = 359)		
	Age	Tanner	% Body fat	Age	Tanner	% Body fat	Age	Tanner	% Body fat
BMI (kg/m^2)	0.54	0.46	0.88	0.55	0.46	0.89	0.53	0.49	0.87
Adjusted BMI (kg/m^2)*	−0.02	0.13	0.82	0.02	0.10	0.82	0.02	0.12	0.82
CDC z score of BMI‡	0.28	0.30	0.88	0.29	0.29	0.88	0.27	0.32	0.88
Frisancho z score of BMI†	0.26	0.28	0.87	0.28	0.28	0.89	0.24	0.31	0.87
CDC percentile of BMI‡	0.28	0.30	0.88	0.29	0.29	0.88	0.27	0.33	0.88

* Log-transformed BMI adjusted for age and gender.
† Based on Frisancho's data (20).
‡ Based on the CDC reference data (19).

(Table 2). When the sample was restricted to children below the 99th age- and gender-specific percentile of BMI, the Spearman correlations with percentage body fat were slightly attenuated for all of the metrics: age- and gender-adjusted BMI ($r = 0.75$), age- and gender-specific z score of BMI ($r = 0.81$ to 0.82), or age- and gender-specific percentile of BMI ($r = 0.82$).

Linear regression models with gender, age, age squared, race, and log-transformed BMI as predictors explained 81% of the variance (Table 3). When age- and gender-specific z scores of BMI, instead of BMI or log-transformed BMI, were included in regression models, 75% (using Frisancho's reference standards) to 79% (using the CDC reference standards) of the variance was explained. Significantly less of the variance (65%) was explained when age- and gender-specific percentile of BMI was included instead of z score or BMI ($p < 0.01$, Table 3). To assess whether extreme BMI values had an undue influence on the results, the analysis also was performed restricting the sample to children with a BMI below the age- and gender-specific 99th percentile from the CDC standards. Restricting the sample resulted in slightly less of the variance being explained by the BMI metrics. Models with log-transformed BMI explained 79% of the variance (vs. 81% when all children were included in the analysis), and models containing z scores based on the CDC standards explained 74% of the variance (vs. 79% when all children were included). The impact on z scores based on Frisancho's standards (78% vs. 79%) were negligible, and the percentages of the variance explained by percentiles of BMI (65% vs. 65%) were identical when the sample was restricted to children below the 99th age- and gender-specific percentile of BMI.

Even after controlling for BMI, African Americans had slightly lower percentage of body fat. Including race (African Americans vs. whites) in the linear regression models did not significantly increase the amount of the variance explained (data not shown). The associations between the

Table 3. Percent of the variance of percentage body fat explained by measures of BMI (controlling for age, age squared, and race)

	BMI	Log-transformed BMI	z scores based on CDC standards (19)	z scores based on Frisancho's standards (20)	Age-specific percentiles of BMI (CDC standards)
Overall	0.72*	0.81	0.79	0.75	0.65*†
<10 years	0.80	0.84	0.78	0.78	0.59
≥10 years	0.69	0.77	0.80	0.69	0.68
White	0.71	0.80	0.81	0.75	0.66
African American	0.74	0.83	0.80	0.78	0.65

* Significantly different from log-transformed BMI ($p < 0.01$).
† Significantly different from z-scores based on CDC standards ($p < 0.001$).

Table 4. Gender-specific estimates of the percent of the variance of percentage body fat explained by the various measures of weight and height (controlling for age, age squared, and race)

	BMI		Log BMI		*z* scores based on CDC standards (19)		*z* scores based on Frisancho's standards (20)		Age-specific percentiles of BMI (CDC standards)	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
Overall	0.69	0.75	0.78	0.84	0.81	0.82	0.74	0.79	0.70	0.62
<10 years	0.80	0.81	0.84	0.84	0.79	0.76	0.77	0.80	0.65	0.52
≥10 years	0.65	0.74	0.72	0.83	0.78	0.88	0.66	0.72	0.71	0.72
White	0.68	0.74	0.77	0.83	0.81	0.82	0.71	0.79	0.71	0.63
African American	0.73	0.77	0.81	0.86	0.81	0.84	0.78	0.79	0.70	0.64

BMI metrics and percentage body fat were similar among African Americans and whites (Table 3).

Controlling for Tanner stage of development did not have an impact in either gender on the ability of the metrics to predict percentage body fat (data not shown). However, there was evidence that the results varied by age and gender (Table 4). With the exception of age- and gender-specific percentiles of BMI, the percent of variance explained was greater among the boys. Among children younger than 10 years of age, the gender difference in the amount of variance explained was minor for BMI and *z* scores. However, among the children who were at least 10 years of age, 6% to 11% more of the variance was explained among the boys. Among the younger children, models with log BMI explained more of the variance ($r^2 = 0.84$) than the other BMI metrics (Table 3). *z* Scores based on CDC reference data were equivalent to *z* scores based on Frisancho's reference data among the younger children, but among the children 10 year of age and older, the latter explained less of the variance (Tables 3 and 4). The age- and gender-specific percentiles of BMI had a different pattern of association than the other BMI metrics with percentage body fat. The percent of the variance explained by percentiles of BMI was equal or higher among the girls (Table 4).

Using overfatness defined by percentage body fat based on the standards proposed by Himes and Bouchard (21), the sensitivity, specificity, and PPVs were highest when *z* scores were used to classify children (0.84, 0.96, and 0.98, respectively, for *z* score ≥1) (Table 5). Using BMI percentiles to define overfatness (i.e., BMI ≥ 95th percentile for age and gender) resulted in a high specificity and PPV, but the sensitivity was only moderate (0.65). However, using a BMI ≥ 85th percentile as the screen improved the sensitivity while maintaining a high specificity (0.82 and 0.96, respectively). Although the adult BMI cutoff value for overweight (BMI ≥ 25 kg/m^2) had excellent specificity (100%) and PPV (100%), the sensitivity was low (0.56). The best BMI criterion for screening for overfatness was a BMI ≥ 20 (sensitivity = 0.80, specificity = 0.97, and PPV = 0.99). For all of the BMI metrics, the sensitivities were higher, and the specificities and predictive values were slighter lower among the boys compared with girls (data not shown). The area under the ROC curves (i.e., the overall predictive ability) was 0.96 for all of the BMI metrics.

Discussion

In a large cohort of children and adolescents, we evaluated the relationship between various metrics of BMI in terms of how well they captured percentage body fat. The Spearman correlations were virtually identical for the BMI metrics with percentage body fat, indicating that in terms of ranking subjects, the measures are interchangeable. However, in terms of explaining percentage body fat, we observed that log-transformed BMI and age- and gender-specific *z* scores of BMI were superior to age- and gender-specific percentiles of BMI. Although the latter metric is probably the most interpretable to the general public, our results would suggest that it is not ideal to use BMI percentile when desiring to explain percentage body fat. Nevertheless, it may be a useful metric in other contexts, such as evaluating effects within weight strata that are less crude than overweight vs. not overweight. For example, one could contrast the effects for those between the 50th and 95th percentile with those between the 10th and 50th percentiles. Moreover, when explaining weight status to patients and their caregivers, it may be useful to convert BMI or *z* score results into percentiles to make the messages easier to interpret.

The choice of whether to use BMI or age- and gender-specific *z* scores of BMI in analyses will depend on several factors, including the age of the sample. If one is studying a narrow age range, BMI and changes in BMI are more interpretable than when one is studying a wide age range.

Table 5. Sensitivity, specificity, and PPV of BMI metrics

	Sensitivity	Specificity	PPV
BMI percentiles			
At risk of overweight (BMI ≥ 85th percentile)	0.82	0.96	0.98
Overweight (BMI ≥ 95th percentile)	0.65	0.99	0.99
BMI			
BMI ≥ 19	0.87	0.89	0.96
BMI ≥ 20	0.80	0.97	0.99
BMI ≥ 21	0.74	0.99	1.00
BMI ≥ 23	0.64	1.00	1.00
BMI ≥ 25	0.56	1.00	1.00
z Scores based on CDC standards (19)			
z score ≥ 1	0.84	0.96	0.98
z score ≥ 2	0.51	1.00	1.00
z score ≥ 3	NA	NA	NA
z scores based on Frisancho's standards (20)			
z score ≥ 1	0.76	0.97	0.99
z score ≥ 2	0.61	0.99	0.99
z score ≥ 3	0.43	1.00	1.00

NA, no child had a *z* score ≥ 3.

We observed that among children <10 years of age, BMI explained more of the variance than did the *z* scores, suggesting that it may be a useful metric at younger ages. Among older children, the *z* scores based on the CDC reference standards explained approximately the same amount of the variance explained by BMI. The advantage of using BMI is that it is widely used by many researchers; however, the disadvantage is that it is not very interpretable without additional information, such as age and gender. The one exception would be high BMI values that would be considered overweight at any age, such as BMI values ≥ 25 kg/m^2 (the adult cutoff for overweight). The advantage of using *z* scores is that they have the same meaning in both genders and at all ages; however, it is not clear how well most lay people understand *z* scores.

The correlation coefficients we observed between BMI and percentage body fat are similar to those reported by Mei et al. (10), who compared BMI-for age, the Rohrer index, and weight-for-height to body fat assessed by DXA among 920 children and adolescents from the U.S., Italy, and New Zealand. They observed that the correlations with BMI-for age ranged from 0.81 to 0.88 for 6- to 19-year-old children and adolescents in their study. The correlations are also similar to those observed by Daniels et al. (9) Our study builds on this work and compares several metrics based on BMI as measures of body fatness.

One limitation to correlation coefficients is that they are a measure of the degree of association, but they do not provide information on the accuracy of the measures being correlated. For example, a measure that consistently underestimated the true value of the predictor variable could have the same correlation with the outcome as a metric that accurately measured the predictor variable. Therefore, when evaluating the merits of a measure, it is advisable to consider more than correlation coefficients. To evaluate the utility of BMI metrics as screening tools, one should assess the sensitivity, specificity, and predictive values or ROC curves of the metrics against a gold standard. It is difficult to compare out results on the sensitivity, specificity, and predictive value of the BMI metrics with other studies because a variety of gold standards have been used, and some studies have combined adolescents and adult samples. Lazarus et al. (8) observed that compared with using percentage total body fat at or above the internally derived 85th percentile, classifying children and adolescents at or above the 85th percentile for age and gender according to National Health and Nutrition Examination Survey I data (collected in 1971 to 1974) as "at risk for overweight" resulted in a 0.72 true positive rate (i.e., sensitivity) for boys and 0.85 for girls. However, the true positive rate was much lower when overweight was defined as greater than or equal to the 95th percentile. Despite using different cutoff values for both variables of interest, their findings are similar to ours, with the exception that we observed higher sensitivity among the boys. It is somewhat more difficult to compare our results with those of Taylor and colleagues because they combined women between the ages of 16 and 80 in the analysis (5). Nevertheless, they observed identical area under the ROC curves (0.96) as we did in our sample of children and adolescents.

There are several limitations to the present study. By design, the BMI distribution was highly skewed toward heavier BMIs. It is possible that in a very lean sample, the relative merits of BMI, *z* scores of BMI, and percentiles of BMI would be different. Given the increasing prevalence of obesity, however, evaluating the metrics in a relatively heavy sample may be more useful than knowing how they compare among very lean children and adolescents. Strengths of the study include its large sample size, the adequate numbers of African Americans to conduct stratified analyses, measured weight and height information, and direct estimates of percentage body fat estimates from DXA scans.

In conclusion, in terms of ranking children, BMI, age- and gender-specific percentile of BMI, and age- and gender-specific *z* score of BMI have nearly identical correlations with percentage body fat. Therefore, any of the three metrics would be suitable to rank order subjects. Studies aiming to evaluate percentage body fat more fully, however, should use either BMI (which has been transformed, if necessary, and adjusted for age) or age- and gender-specific *z* score of BMI as their weight metric. Samples comprised of relatively heavy children are well suited for using BMI because high BMI values are interpretable at all ages. Although percentiles of BMI may be the easiest metric to convey to the patients and the general public, our data suggest that they are the least accurate measure; therefore, it may not be advisable to use them as an estimate of percentage body fat for studies that seek to do more than place children in rank order according to fatness. However, if the goal is to screen young people for overfatness, *z* scores and percentiles and BMI values over 20 kg/m^2 may be useful in both clinical and research settings.

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